ANL/ESD/TM-22
ADDENDUM

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TO: Readers of ANL/ESD/TM-22, Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity

FROM: M. A. DeLuchi

SUBJECT: Effect of 1992 Revision of Global Warming Potential (GWP) by the Intergovernmental Panel on Climate Change (IPCC)

This letter contains two important messages about the enclosed document.

1) This document supersedes all previous versions of this work. Please do not use any older versions any more.

2) The atmospheric-science community now believes that it cannot estimate confidently the "Global Warming Potentials" (GWPs) of the indirect effects of greenhouse gases. (A GWP is a number that converts a mass-unit emission of a greenhouse gas other than CO_2 into the mass amount of CO_2 that has an equivalent warming effect over a given period of time. My report refers to GWPs as "CO_2-equivalency factors".) For example, a forthcoming report by the Intergovernmental Panel on Climate Change (IPCC; forthcoming, May 1992) disavows many of the GWPs estimated in an earlier IPCC report (IPCC, *Climate Change, the IPCC Scientific Assessment*, Cambridge, Cambridge University Press, Cambridge, England, 1990), and states that GWPs for the indirect effects of the non-CO_2 greenhouse gases cannot be estimated accurately yet. However, this does not mean that *in principle* there are no GWPs for the non-CO_2 greenhouse gases; rather, it means that some of the GWPs are uncertain, and that the earlier IPCC estimates of the GWPs may or may not turn out to be right (albeit, in at least one case, discussed below, the earlier estimates almost certainly will be wrong).

In the enclosed report I used the IPCC's 1990 estimates of the GWPs for 20-, 100-, and 500-year time horizons, and expressed the bottom-line results for each of these three time horizons. However, the recent uncertainty about the GWPs affects how you should interpret the results. Because the IPCC has disclaimed some of its GWPs, the GWPs as a group no longer are the best estimates of the warming effects over 20, 100, and 500 years. Instead, they are just a collection of possible values for the GWPs -- in short, *scenarios. Therefore, you should interpret the "20-, 100-, and 500-year time horizons" as three general GWP scenarios -- say, scenarios, A, B, and C. -- and not as time-period scenarios.* For example, you should *not* think that the results shown here under the "100-year time horizon" actually embody the scientific community's best estimates of the relative warming potentials of the various greenhouse gases over a 100-year period. Instead, you should understand the results to be the outcome of making a particular set of assumptions about what the GWPs might be. The "time horizons" no longer necessarily represent time horizons, but rather general scenarios for, or assumptions about, the GWPs.

If somebody does re-estimate the GWPs, and finds that the *entire* set of them are *substantially* different from any GWP scenario used here, then the bottom-line, CO_2-equivalent results shown here will be less useful. (Of course, all the disaggregated results, methods, and other input data are not affected by the uncertainty about GWPs.) In the next section of this letter, I briefly review the status of GWPs for non-CO_2 greenhouse gases, and discuss how the uncertainty affects the interpretation of the results presented in this report.

- CFCs: In a recent article in *Nature* (Vol. 355: 810-812, "Radiative Forcing of Climate from Halocarbon-Induced Global Stratospheric Ozone Loss," 1992), V. Ramaswamy et al. report that the depletion of stratospheric ozone by CFCs is cooling some regions of the atmosphere, and that this cooling may counterbalance the direct warming effect of CFCs. They conclude that the net global warming effect of CFCs is likely to be much less than previously thought. However, others have questioned this conclusion ("Role of Methane in Global Warming Continues to Perplex Scientists," *Chemical and Engineering News*, February 10, 26-28, 1992). In any case, if Ramaswamy et al. are correct, then *the few statements I made in this report about the great warming effect of CFC emissions from automobiles may turn out to be wrong. However, because I did not include CFCs in any of the numerical results shown in Volume 1, none of those results are affected by the uncertainty regarding the GWPs for CFCs.*

- N_2O (nitrous oxide): Because N_2O affects climate only directly (as an infrared absorber), and apparently not in important indirect ways, there is comparatively little uncertainty about its GWP. The updated GWPs for N_2O (IPCC, 1992, forthcoming) are only about 10% lower than the 1990 GWPs used in this report. Thus, *it appears that the GWP for N_2O will not be revised enough to noticeably change the results reported here.* To confirm this, I recalculated some of the base-case emissions totals, using the updated IPCC (1992, forthcoming) GWP for N_2O but holding everything else constant. In most fuel cycles, total gram/mile CO_2-equivalent emissions were only 0.1 to 0.2% lower than the totals reported here based on the 1990 GWP. The total for a couple of the wood-based cycles was 0.7% lower, and the total for the ethanol-from-corn fuel cycle was 1.2% lower than the 1990-GWP-based cycle.

- CO (carbon monoxide): the 1990 GWP for CO consists of two parts: one part that accounts for the eventual oxidation of CO to CO_2, and another that accounts for the role of CO in ozone formation. The part of the GWP that accounts for oxidation to CO_2 is easy to estimate and is not uncertain, and in longer time horizons it is the larger of the two parts. The part of the GWP that accounts for the effect on ozone is now well known, and is the part that the IPCC is now disavowing, but it also is small absolutely: the IPCC estimated in 1990 that it was close to zero over 500 years, and equal to only 1 to 2 over 100 years. Even if these estimates of the ozone effect of CO prove to be off by a factor of two, the effect still will be relatively minor (the ozone-related GWP will be between 1 and 4). *Thus, unless the ozone part of the GWP for CO has been terrifically underestimated, the difference between the true GWP and the 1990 GWP used here probably is not great enough to noticeably affect the results (because the ozone part of the GWP for CO will be so small).* To confirm this, I recalculated some of the base-case emissions totals assuming that the ozone-related warming effect of CO is twice as big as estimated by the IPCC in 1990. In most cases, total gram/mile CO_2-equivalent emissions were within 1% (in a few cases, 4-6%) of the results based on the 1990 GWP. In every case, the percentage change relative to petroleum was within 1 percentage point of the percentage change calculated in this report.

- NMOCs (non-methane organic compounds): the GWP for NMOCs is similar to that for CO, in that it consists of one straightforward component that accounts for oxidation of the carbon to CO_2, and a second uncertain component that accounts for indirect effects of NMOCs on the production of ozone. Although the ozone component of the GWP for NMOCs appears to be larger than the ozone component of the GWP for CO, NMOC mass emissions throughout fuel cycles are much less than CO mass emissions, so that uncertainty in the GWP for NMOCs still is likely to be unimportant. As shown in Table 10 of this report, NMOCs are the least or second-least important greenhouse gas in every fuel cycle. *Thus, unless the ozone component of the 1990 GWP for NMOCs is in error*

by a huge amount, the true GWP probably is not different enough from the 1990 GWP to significantly change the results (because both mass emissions of NMOCs and the ozone part of the GWP are relatively small). For example, I found that even if the ozone-related warming effect of NMOCs is 50% higher than estimated by the IPCC in 1990, the standing of all the nonpetroleum fuel cycles relative to the petroleum cycles was virtually identical to the relative standing based on the 1990 GWP.

- CH4 (methane): The GWP for methane consists of a direct-warming component and an indirect-warming component. IPCC's most recent estimate (1992, forthcoming) of the direct-warming component is about 10-20% higher than the 1990 estimate*. The IPCC has not re-estimated the indirect-warming component, but expects it to be important enough that the total (direct + indirect) GWP for methane will be significantly larger than the direct-warming component alone. According to one recent model, the indirect effects of methane may increase its GWP by 50% to 100% ("Role of Methane in Global Warming Continues to Perplex Scientists," *Chemical and Engineering News*, February 10, 26-28, 1992). This, however, would make the total GWP for methane no greater than total estimated by the IPCC in 1990. (The IPCC estimated in 1990 that the indirect effect was slightly more than 100% of the direct effect.). Nevertheless, *the GWP for methane is large enough, and uncertain enough, that the true GWP might be enough different from the 1990 GWP to significantly alter the results reported here, although there is no evidence yet the true GWP is in fact substantially different from the 1990 GWP.*

- NOx (nitrogen oxides): The GWPs published by the IPCC in 1990 are very high, and make NO_X a surprisingly important greenhouse gas. However, Johnson et al. reported recently in Nature (Volume 355: 69-71, Impact of Aircraft and Surface Emissions of Nitrogen Oxides on Tropospheric Ozone and Global Warming," 1992) that the model used to calculate the 1990 NO_X GWPs had an error that overestimated the GWPs by a factor of 5. Moreover, the forthcoming IPCC (1992) report notes that NO_X emissions have indirect effects that tend to counteract global warming, so that it is not even clear if the net GWP for NO_X should be positive. Although I did not learn of the error in the IPCC model, or of the revised IPCC position until recently, I doubted the 1990 GWPs for NO_X, and in my report qualified many of my statements about the importance of NO_X emissions. (For example, see section 4.2.4, paragraph 2, where I describe the GWP for NO_X as "relatively high and very uncertain"; section 5.2, where I exclude NO_X and NMOCs from my model; section 5.9, where I refer to GWP for NO_X as "dubious" and "perhaps implausible"; section 6.1.6; and Appendix O of Volume II.) In light of the IPCC's overestimation of the GWPs for NO_X, I will reiterate these qualifications here: *when you read my discussions of the role of NO_X emissions, keep in mind that the 1990 IPCC GWP was overestimated by a factor of 5, and that the GWP for NOx might even be zero. You might even want to ignore statements in this report about the potentially great importance of NO_X emissions. If the GWP for NO_X is close to zero, then the results of my scenarios 4, 5, 6 may be most accurate.*

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* The 1990 IPCC report shows the indirect-warming component of the GWP for methane and the total (direct plus indirect) GWP, but not the direct-warming component alone. One could infer the direct component by subtracting the indirect component from the total. However, because of a typographical error in the IPCC report, the shown total indirect component is wrong (it is too high), and so if one calculated the direct GWP by subtracting the shown (misprinted) indirect component from the shown total, one would get the wrong answer (the resultant direct would be too low). When I say here that the 1992 estimate of the direct component is close to the 1990 estimate, I am referring to the correct (not shown) 1990 estimate, not the one would have gotten by subtracting the (misprinted) indirect component from the total.

The bottom line, then, is this: the GWP for CFC-12 is not relevant to this report because I do not include CFCs in any results of Volume I; the 1990 GWPs for CO and NMOCs would have to be in error by an improbably large amount in order to noticeably alter the results reported here; the GWP for CH_4 is uncertain and important, and *might* change enough to affect the results; and the 1990 GWP for NO_x is almost certainly wrong. The problem really boils down to the GWP for NO_x and *perhaps* the GWP for the indirect effects of CH_4. So again: please interpret the time horizons used here as "what if" scenarios for the GWPs, not as definitive estimates of warming effects over different periods. The following table provides another "what if" scenario: it shows the results of assuming a GWP of 21 for CH_4, 3 for CO, 270 for N_2O, 13 for NMOCs, and O for NO_2.

Base-case results for another GWP scenario analysis

	Gasoline LDV	Methanol LDV	CNG LDV	Hydrogen LDV	Ethanol LDV	LPG LDV
Total CO_2-equivalent g/mi emissions	455	436	389	164	504	350
Percentage change relative to gas or diesel		-4.7	-15.1	-64.2	10.3	-23.5
	Diesel HDV	Methanol HDV	CNG HDV	Hydrogen HDV	Ethanol LDV	LPG LDV
Total CO_2-equivalent g/mi emissions	2249	2627	2373	902	3157	2200
Percentage change relative to gas or diesel		16.8	5.5	-59.9	40.4	-2.1
		Wood-methanol LDV	Wood-CNG LDV		Wood-ethanol LDV	
Total CO_2-equivalent g/mi emissions		158	205		86	
Percentage change relative to gas or diesel		-65.1	-55.3		-81.0	

Assuming a GWP of 21 for CH_4, 3 for CO, 13 for NMOCs (carbon portion only), 270 for N_2O, and O for NO_x. Emissions from vehicle manufacture and assembly also were reduced very slightly (about 1%).

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